Caterpillar

AccuGrade GPS & ATS Systems

Road Construction

Production Study

MALAGA Demonstration & Learning Center

December 2006

CATERPILLAR®

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Appendix

Abstract

A productivity study on AccuGrade systems was conducted from November 25th to December 1st 2006 at the Malaga Demonstration and Learning Centre MDLC, Spain.

The purpose of the study was to measure the productivity increase using AccuGrade systems on a road design example, which could simulate a highway access road or similar. The road was 80 meters long and included cuts and fills, curves, elevation changes and super elevations.

Two identical roads were built, one using the “Conventional Way” with stakes on the ground and the “New Way” using Machine Control AccuGrade systems.
The production study consisted in measuring the time for all different operations, the number of passes, buckets or truckloads, fuel consumption and accuracies to compare the two methods.

To ensure consistency, the two roads were built in the same area close together and used the same materials. The same machine models, the same machine operators were used and operations took place with the same weather conditions.

The results of the productivity study are as follows:

- Overall time for building the road was 3½ days vs. 1½ with AccuGrade
- Increase in overall job site productivity on 101%
- Higher and more consistent accuracy
- 43% fuel saving

These results are better than those commonly announced on Machine Control & Guidance products through customers’ testimonial or advertisements.

Analysis demonstrated that productivity and unit cost improvements result from a reduction in surveying support, increase in operational efficiency for earthmoving, and decrease in number of passes.

1 – Introduction

Some call it the biggest change in land development since the Industrial Revolution. They're talking about the technology boom that is transforming the way design engineers, contractors, and job-site crews can tackle their grading and excavation jobs. What used to be done manually can now be completed more efficiently and accurately with Machine control systems.

This is exactly what this production study is trying to point out on a road construction example by measuring operations time, passes, consumptions and accuracies. Two identical roads were built, one using the "Conventional Way" with stakes on the ground and the "New Way" using Machine Control AccuGrade systems, with the aim of measuring the productivity increase of the entire job site.

The relatively complex road design with continuous changes in slope and super elevation proposed means that this productivity study can be applicable to highway intersections, roundabouts and other complex designs even if we all know that each job site is different.

After an overview of personnel and machine equipment used, the project description details the site preparation, the geometrical definition of the design and lists the different elements measured for the productivity study.
Chapter 3 contains a detailed chronological report split into the relevant stages (staking, bulk earthmoving, sub-grade grading, base course grading and base course fine grading). Grade check results are provided after the sub-grade and the base course construction for both ways to highlight difference in accuracy and quality.

In chapter 4 you will find a summary of the results accompanied by related calculations for productivity increase. The findings are presented in terms of productivity increase, fuel consumption, number of buckets and truck loads as well as number of passes. Finally there is a summary of man hours used for the foreman, surveyor and helper for the two methods.

Personnel

The following persons were involved in this study:

	Position
Marilyn Murphy	Project leader – Timekeeper
Arm Abaza	Logistic - Timekeeper
Andreas Mlinsk,	330D operator
Siegbert Jeschke	D6N and 140H operator
Ronny Antunez	Articulated Truck and Roller Operator
Kelly Todd	Articulated Truck and Roller Operator
Gary Martin	Foreman
Eric Durand	Surveyor
Kjeld Jepersen	helper
Rogier Tonies	helper
Jim Shoon	helper
Mike Naylor	Video

Equipment

Conventional Way		Using AccuGrade Machine Control systems	
	D6N		D6N with AccuGrade GPS v6.1
	330D		330D AccuGrade GPS Hex
	725 for cuts & fills 730 for cuts & fills and for base course construction 740 ejector for base course		725 for cuts & fills 730 for cuts & fills and for base course construction 740 ejector for base course
	CS 563		CS 563
	140H		140H with AccuGrade ATS
	Trimble 5800 rover kit for surveying		ATS

2 – Project description

2.1 – Site location

The project took place in the New Land area at Malaga Demonstration and Learning Center (MDLC)

2.2 – Site preparation

Initially, the two pads used were leveled using the D8T equipped with AccuGrade GPS in order to be able to create two identical road designs.

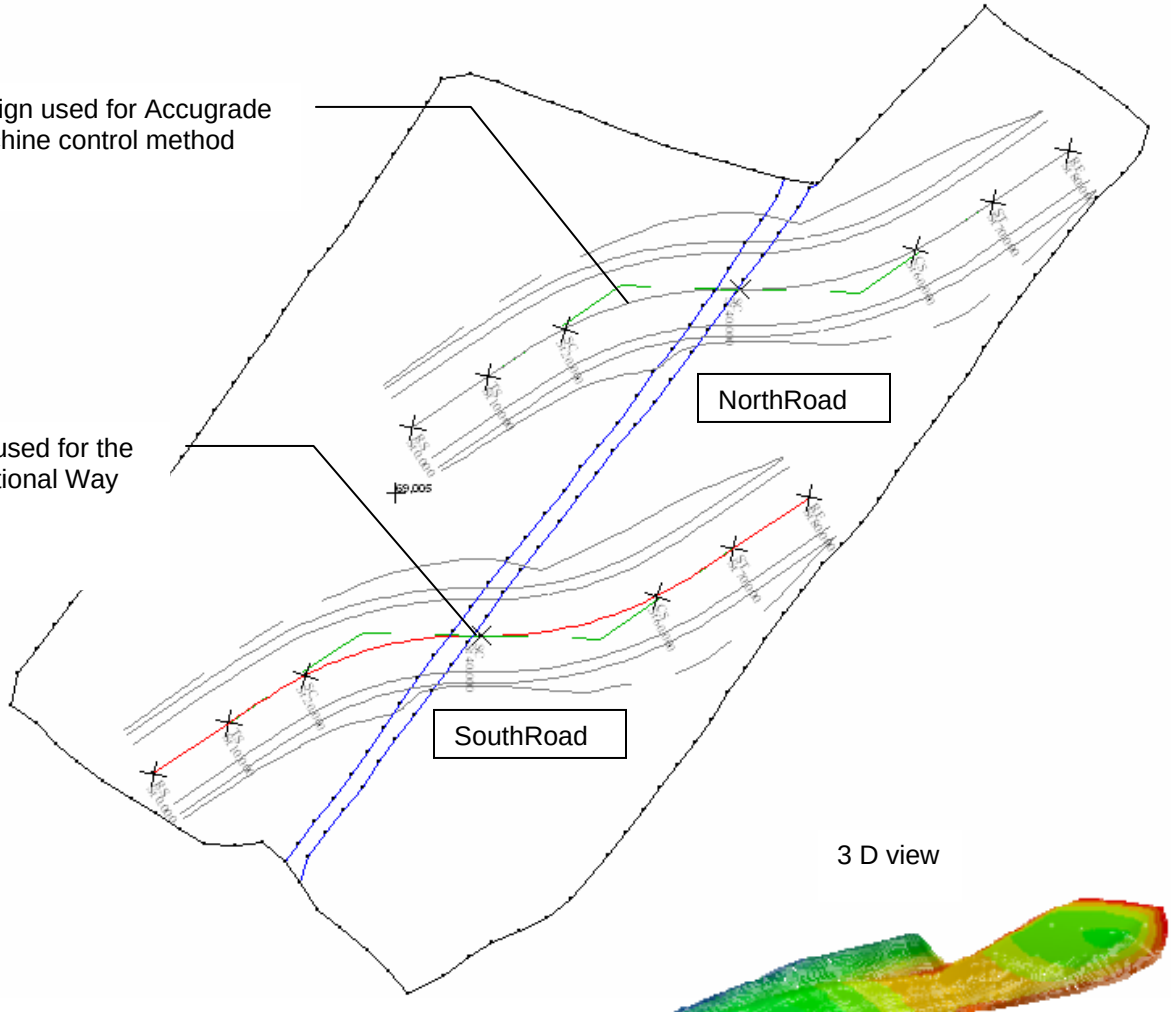
The two pads were surveyed using a Trimble 5800 GPS rover to compute accurate volumes of cuts and fills for both designs.

2.3 – Design preparation

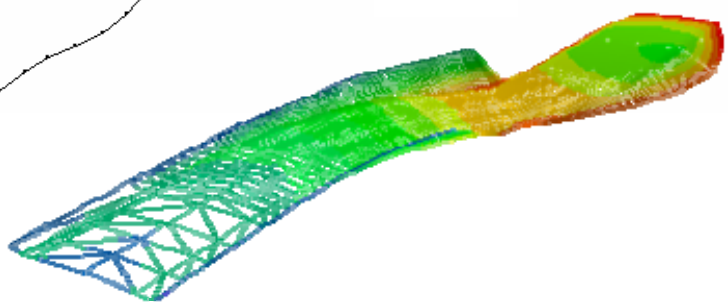
Two identical road designs were prepared to fit into the given area.

Design used for Accugrade machine control method

Design used for the Conventional Way method



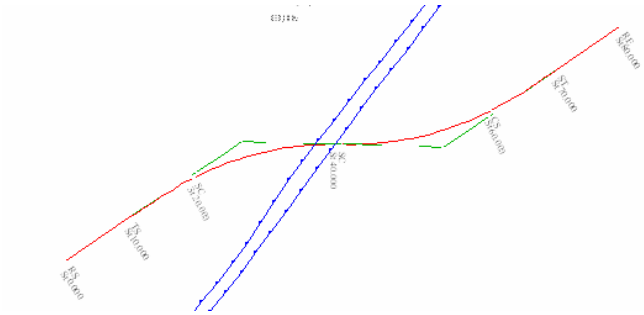
3 D view



2.3.1 Horizontal Alignment

The horizontal alignment includes the following elements and is 80 meters long:

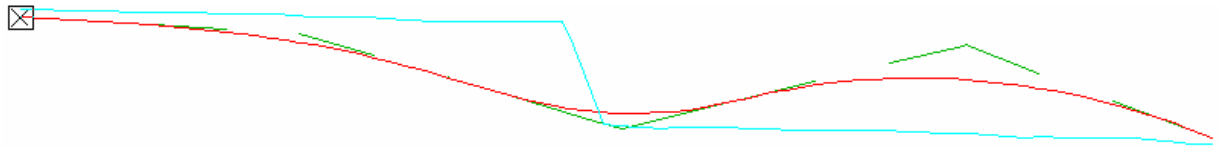
Element	Azimuth	Radius	Length	Station
Point				0.000
Line	62.0000		10.000	10.000
Spiral			10.000	20.000
Arc		40.000	20.000	40.000
Arc		-40.000	20.000	60.000
Spiral			10.000	70.000
Line	62.0000		10.000	80.000



2.3.2 vertical Alignment

The vertical alignment includes three symmetric parabolas. The difference between the highest point and the lowest point is 2.40 meters.

Profile view

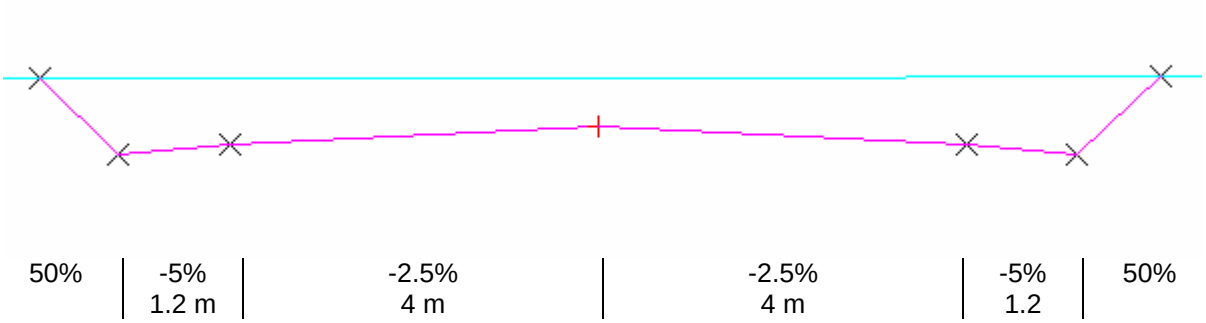


The blue line represents the natural terrain along the Master alignment.
The red line represents the design.

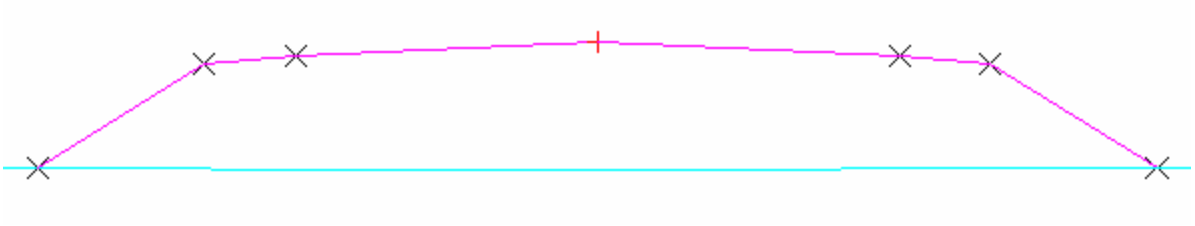
2.3.3 Cross Sections

The template applied along the road is:

For the cutting area



For the filling area



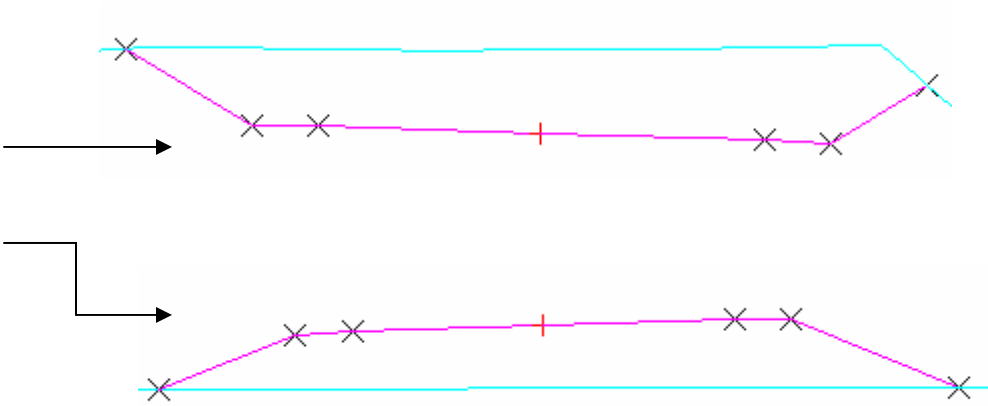
-33%	-5% 1.2 m	-2.5% 4 m	-2.5% 4 m	-5% 1.2	-33%

2.3.4 Super elevation

The following table was applied to the road

Superelevation

Station	Left	Right
0.000	-2.500%	-2.500%
10.000	-2.500%	-2.500%
30.000	2.500%	-2.500%
40.000	0.000%	0.000%
60.000	-2.500%	2.500%
70.000	-2.500%	-2.500%
80.000	-2.500%	-2.500%

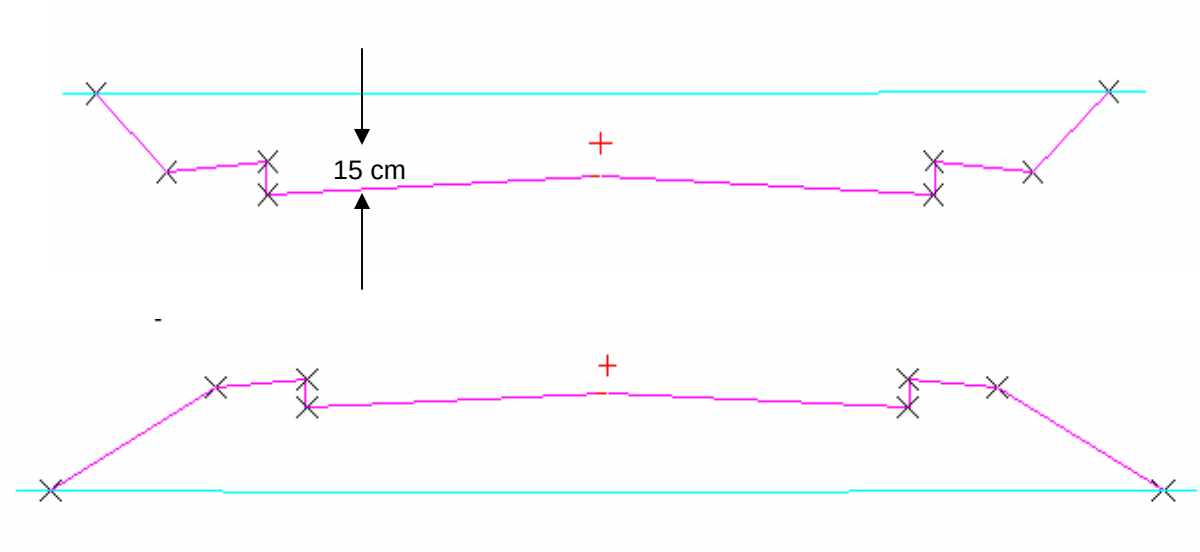


2.3.5 Volumes

Road	Cut	Fill
SouthRoad	357 m^3	347 m^3
NorthRoad	358 m^3	348 m^3

2.3.6 Subgrade

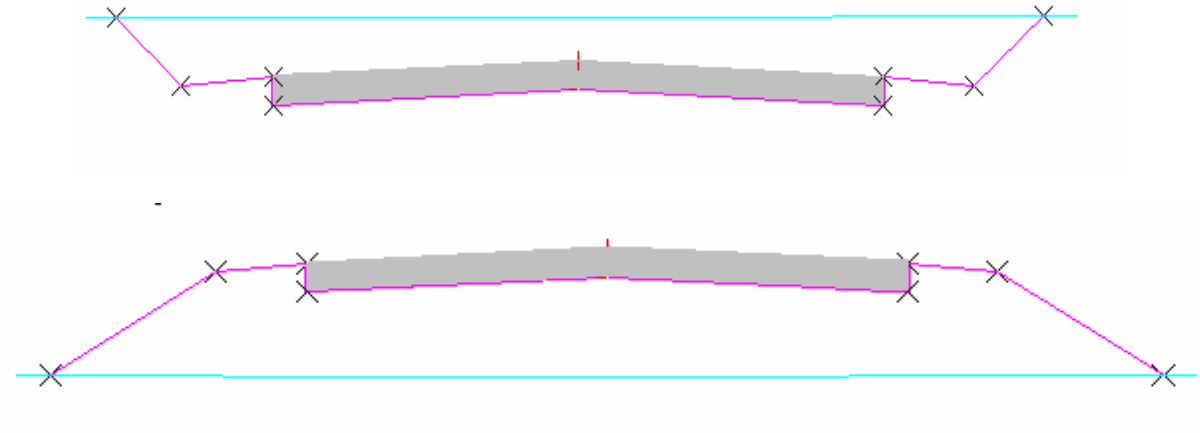
The subgrade is basically the native or imported soil prepared to support loads transferred from the base course and/or vehicle wheel loads. A proper subgrade must be in place before the road can be based and surfaced.
This work includes removal of unsuitable soils, cutting and filling to achieve proper grades, compaction of soils.



The carriage way for the subgrade was graded 15 cm below the design.

2.3.7 Base Course

Commonly referred to as "base". It consists of a thick layer of highly compacted crushed gravel. A proper base course must be in place prior to surfacing. The base course shall be a minimum depth of 150mm.



2.4 – Survey equipment

2.4.1 GPS Base station

The base station from MDLC located in La Casa restaurant was used during all operation. The receiver is a Trimble MS750 with 13” rugged antenna. The radio is a Sitenet 450 broadcasting Compact Measurement Record CMR+.

2.4.2 GPS Rover

A Trimble 5800 GPS rover kit with Survey Controller software was used for the staking out process for SouthRoad design for the conventional method.
This rover was also used for Grade checking for both SouthRoad and NorthRoad design using SCS900 software.

2.4.3 Accessories

Stakes

400x 40x40 mm
1000x40x20 mm

Level

String line

Tape measure

2.5 - Machine Control Equipment

The same machines equipped with Accugrade systems were used on NorthRoad design.

AccuGrade GPS version 6.1

AccuGrade GPS version 6.1

AccuGrade ATS version 6.1

2.6 – Production Study

The production study consisted in measuring the following elements to compare the two methods. The “Conventional Way” using stakes on the ground and the “New Way” using Machine Control Accugrade systems.

	Conventional Way	AccuGade machine Control
General measurements		
 Staking	Time	
 Fuel consumption	D6N 330D 14H	D6N 330D 14H
Bulk Earthworks measurements		
	D6N 330D	Total of number of passes Total time (hours) Total Number of bucket Total of truck loads Total Time (hours)
Subgrade Fine grading measurements		
	D6N 330D	Total of number of passes Total time (hours) Total Time (hours)
Subgrade Checking		
	The Subgrade is surveyed to check tolerances	
Base Course fine grading measurements		
	330D D6N 140H	Total of number of truck load Total of number of buckets Total of number of passes Total time (hours) Total of number of passes Total time (hours)
Base Course Checking		

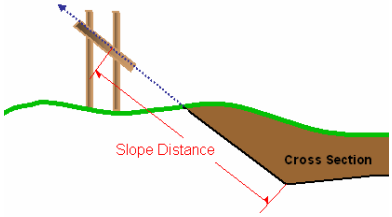
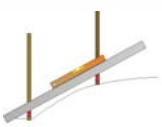
	The base is surveyed to check tolerances

3 – Operations

Operations started on Saturday 25th of November and finished on Friday 1st of December.

Office preparation time is not reported in results because the same design was used for both ways. Digital data were downloaded in the control unit of the survey equipment for the Conventional Way and on the data cards for machines for the New Way. Trimble Geomatics Office and AccuGrade Office software were used for data preparation.

3.1 - Staking out

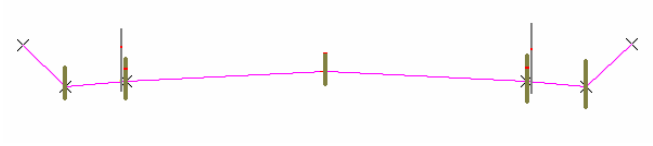
Conventional Way	New Way – AccuGrade
Design: SouthRoad	Design: NorthRoad
Slope rails have been setout on both side of the road every ten meters. Points were staked out using GPS rover and level was used to define the slope of the rails.  The Slope distance to the hinge point was reported on the stake. 	Only one stake was used for the system checks on the blade tips.  This stake was setout near the beginning of the road.
02:15 — 45	00:03 — 1

Number of stakes

3.2 – Bulk Earthwork

Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Machine: D6N	**Machine**: D6N
	
04:40 Passes 259	04:18 Passes 200
Machine: 330D	**Machine**: 330D
	
02:23 234 31	01:53 176 23

3.3 – More Staking

Conventional Way	New Way – AccuGrade
Design: SouthRoad	Design: NorthRoad
 Five stakes per cross sections were setout for fine grading the subgrade and the base course (5x9=45). Two long stakes were used for cross slope grading for each cross section (2x9=18). Six stakes were destroyed. 	
05:16 69	00:00 0

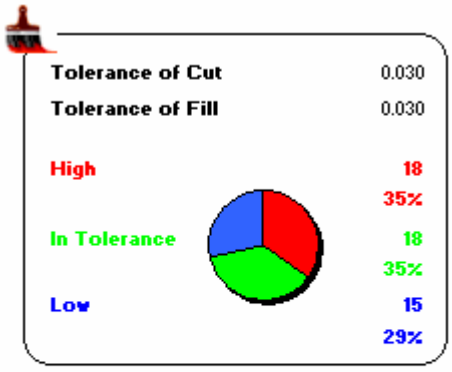
3.4 – Subgrade Fine Grading

Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Machine: D6N	**Machine**: D6N
	
03:48 Passes 214	01:28 Passes 60
Machine: 330D	**Machine**: 330D
	
02:56	02:43

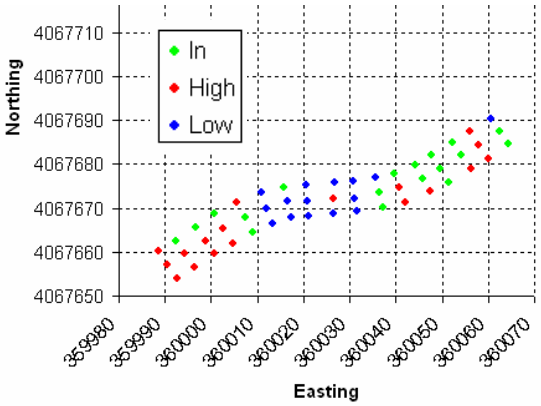
Machine: CS 563	**Machine**: CS 563
Compaction: 4 passes	Compaction: 4 passes
	

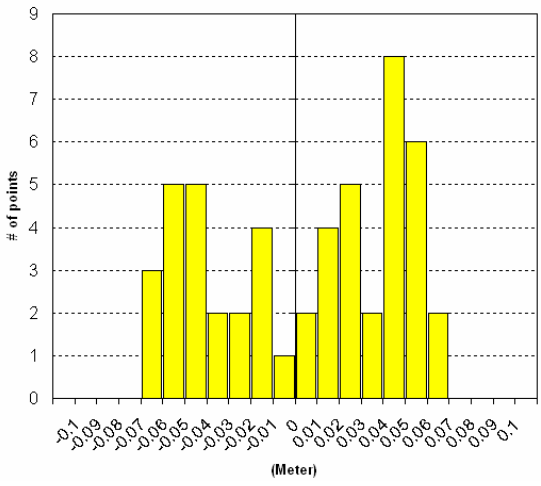
3.5 – Subgrade checking

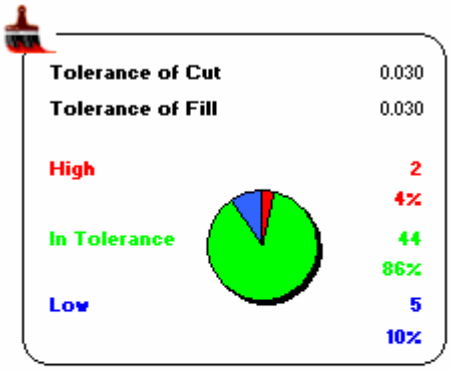
Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Equipment: Trimble 5800 + SCS900 software	**Equipment**: Trimble 5800 + SCS900 software
Three points every 5 m were surveyed on the carriageway. A tolerance of ± 3 cm was applied	Three points every 5 m were surveyed on the carriageway. A tolerance of ± 3 cm was applied



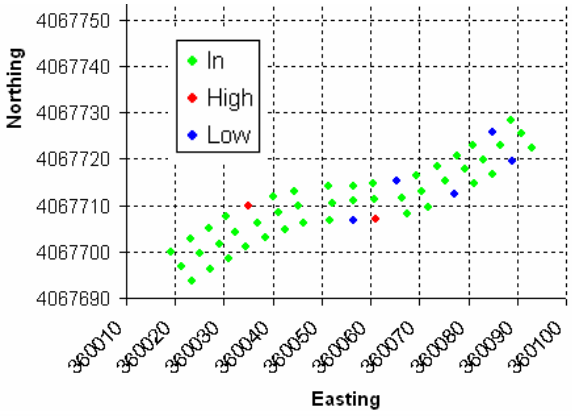
Maximum Cut	0.069 m
Average Cut	0.050 m
Maximum Fill	-0.067 m
Average Fill	-0.050 m

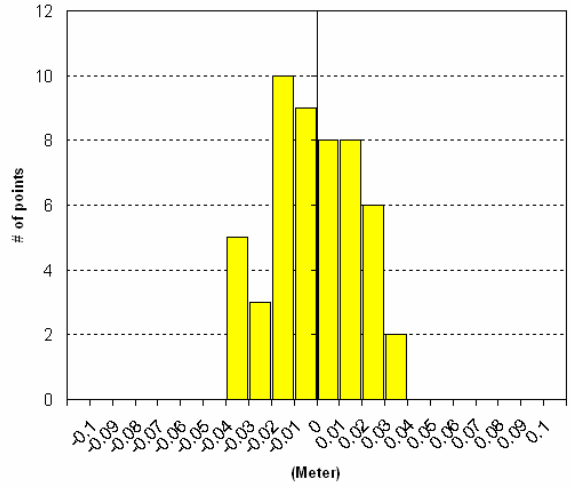






Maximum Cut	0.030 m
Average Cut	0.030 m
Maximum Fill	-0.039 m
Average Fill	-0.035 m





3.6 - Base Course construction

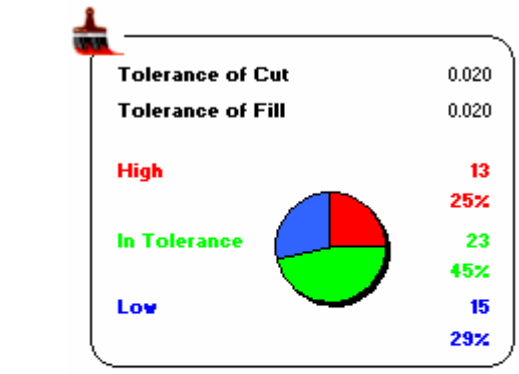
Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Machine: D6N	**Machine**: D6N
	
02:24 Passes 156	00:53 Passes 46
Number of passes for 10 m Station 10 m 40 20 m 30 30 m 31 40 m 15 50 m 4 60 m 10 70 m 12 80 m 14	Number of passes for 10 m Station 10 m 12 20 m 12 30 m 5 40 m 5 50 m 5 60 m 5 70 m 1 80 m 1
Machines: 330D – 730 – 740	**Machines**: 330D – 730 – 740
	
730 5 truck loads 740 4 truck loads	730 3 truck loads 740 5 truck loads
74 9	69 8

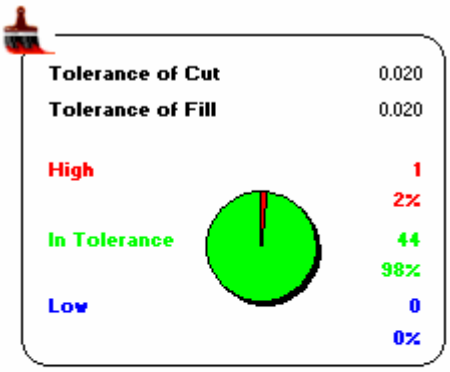
3.7 - Base Course fine grading

Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Survey:	**Survey:** Three control points surveyed around the working area and ATS System setup.
	
00:00	00:51
Machine: 140H	**Machine**: 140H
	
01:49 Passes 62	00:32 Passes 17
Machine: CS 563	**Machine**: CS 563
Compaction : 4 passes	Compaction : 4 passes
	

3.8 - Base Course grade check

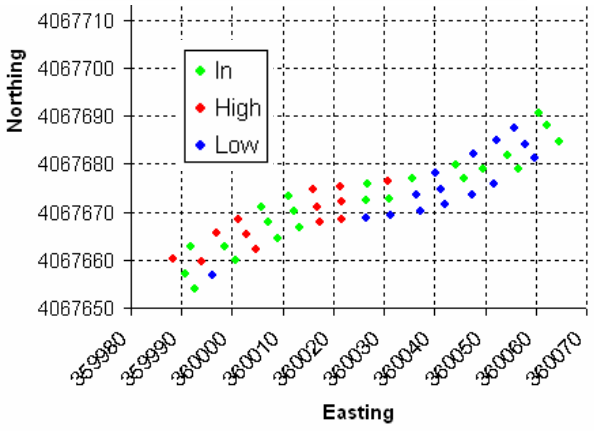
Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
Equipment: Trimble 5800 + SCS900 software	**Equipment**: Trimble 5800 + SCS900 software
Three points every 5 m were surveyed on the carriageway. A tolerance of ± 2 cm was applied	Three points every 5 m were surveyed on the carriageway. A tolerance of ± 2 cm was applied

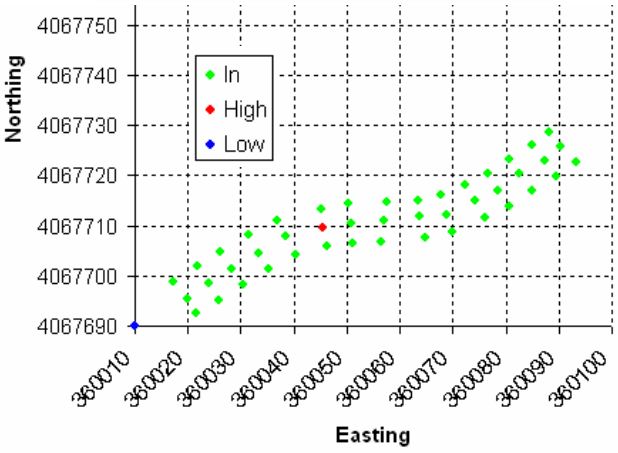


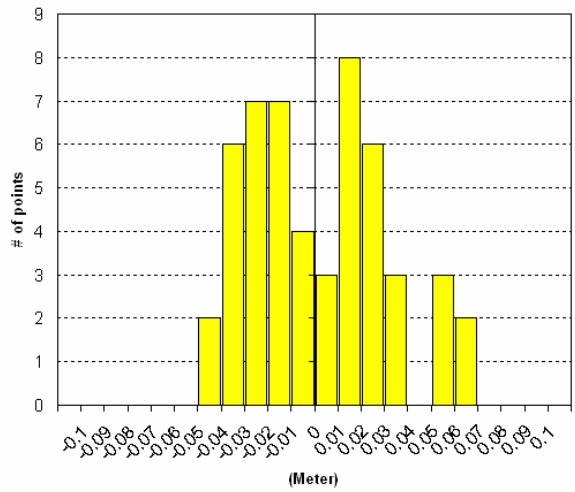


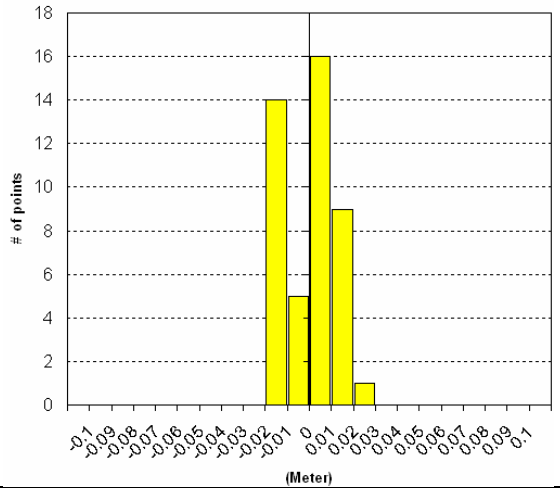
Maximum Cut	0.063 m
Average Cut	0.040 m
Maximum Fill	-0.046 m
Average Fill	-0.032 m

Maximum Cut	0.025 m
Average Cut	0.025 m
Maximum Fill	-
Average Fill	-

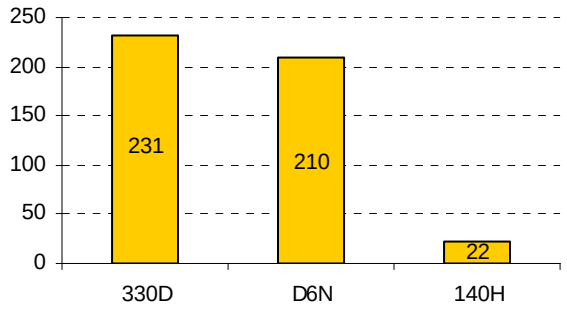
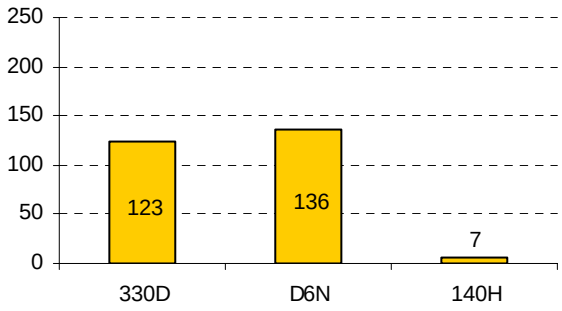






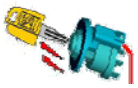


3.9 – Fuel consumption

Conventional Way	New Way – AccuGrade
Design: SouthRoad	**Design**: NorthRoad
	

4 – Results

		Conventional Way	New Way AccuGrade	Productivity Gain
 Staking		07:31	00:54	6:37 hours saved
 Bulk Earthmoving	**D6N** **330D**	04:40 02:23	04:18 01:53	+ 9 % + 27 %
 Subgrade grading	**D6N** **330D**	03:48 02:56	01:28 02:43	+ 159 % + 8 %
 Base Course grading	**D6N**	02:24	00:53	+ 172 %
 Base course fine grading	**140H**	01:49	00.32	+ 241%
Total		**24:32**	**11:50**	**+ 101%**



		Conventional Way	New Way	Productivity Gain
	Passes 	Earthmoving 259 Sub Fine Grading 214 Base course 156 **Total 632**	Earthmoving. 200 Sub Fine Grading 60 Base course 46 **Total 306**	+ 30 % + 257 % + 239 **%** **+ 107 %**
		210 l	136 l	**35% saved**
	 	Earthmoving 234 Base course 74 **Total 308** Earthmoving 31 Base course 9 **Total 40**	Earthmoving 176 Base course 69 **Total 245** Earthmoving. 23 Base course 8 **Total 31**	+ 32 % + 7 % **+ 26 %** **+ 29 %**
		231 l	123 l	**47% saved**
	Passes 	Base course 62	Base course 17	**+ 265 %**
		22 l	7 l	**68% saved**

Additional Head count		Conventional Way	New Way	Gain
	Foreman	Full Time **24:32 hours**	Full Time **11:50 hours**	**Half time**
	Operators (x4)	98:08 hours	47:20 hours	**Half time**
	Surveyor	18:14 hours	00:54 hours	**95 % of time saved**
	Worker	18:14 hours	-	**1 person less**

Accuracy		Conventional Way % in Tolerance of ± 3 cm	New Way % in Tolerance of ± 2 cm
	Subgrade	35%	86%
	Base course	45%	98%

Note: The weather conditions were exactly the same for both Ways, sunny and the soil was dry.

Comments

In this case, the New Way method simply took **one and a half days** when the Conventional Way took **three and a half days**.

We used to hear from customer testimonials or advertising that these technology attachments to machines are providing customers with 30%-plus productivity gains. In that study configuration where a **TTT**, an excavator and a grader were equipped with AccuGrade, the productivity gain reaches 101% meaning twice faster with less than half the passes and two times more accurate.

The total fuel consumption difference between the two methods represents 43% saved for three machines. (266 versus 463 liters)

Those results show the biggest productivity gain for grading and fine grading operations. Time is divided by more than 2 for the dozer and more than 3 for the grader. The number of passes is divided by 3 for both the **TTT** and the grader. But we shouldn't forget that the closer to the final grade you are on earthmoving operations, the faster the time for grading will be.

However, the results by themselves don't highlight all the advantages of the AccuGrade system on the excavator for the following reasons:

1.The excavator actually did more work on the New Way than on the Conventional and was used more efficiently. Not only, batters and shoulders were more accurately graded but also the carriage way was entirely graded accurately on the cut area. This made the fine grading of the subgrade easier and faster for the dozer, the cut area was practically done for him. This explains why there is only 8% of time difference (13 min) in the Subgrade grading between the two ways for the Excavator.
2.On the earthmoving part, the number of buckets saved for the same volume of dirt between the two ways is 32%. This really relates directly to the efficiency of the machine and explains part of the fuel consumption saving of 47% for the excavator.

3.The performance for the base course regarding the number of buckets and the number of trucks loaded doesn’t belong to the excavator performance but to the **TTT** performance in terms of the quality of grading. A more accurate grading can save material and truck runs.

Of course, the accuracy of the grading can always be improved on the Conventional Way and can certainly be better than the results obtained here. But we've never seen accuracy as good as that provided by AccuGrade for the grading machines on the entire job site plus, in half the period of time with less people.

Job size seems to have played a significant role in the acceptance of guidance and control technologies. One contractor says his system paid for itself "in three months on that job alone." Another reports excellent productivity improvement at a project that involved a few million cubic meters of soil. But jobs that take several months or involve thousands of m^2 of ground are rare. This study also shows that even for quite small jobs, Machine Control and Guidance products can make jobs more efficient, accurate and profitable.

The study also shows the benefits of AccuGrade for each machine and can help to make a choice. If the customer is just getting started in this and does mostly small-site jobs, the best bet would probably be to put it on a finish **TTT** first. If he is laying rock for a major highway project, he'd probably want to equip a motor grader. If he is doing mass earthmoving and he is loading off-road trucks, an excavator is a good application and maybe on the same job, a dozer in the fill area?

5 - Conclusion

The above results confirm that machine control and guidance has revolutionized the construction industry by making it possible for jobs to be completed more quickly, at lower cost and with the highest degree of accuracy.

Analysis demonstrated that productivity and unit cost improvements result from a reduction in surveying support, increase in operational efficiency for earthmoving, drastically decrease in number of passes for fine grading and saved fuel consumption.